Long-term follow-up and amputation-free survival in 497 casualties with combat-related vascular injuries and damage-control resuscitation

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BACKGROUND: The effectiveness of damage-control resuscitation (DCR) has been demonstrated in recent US conflicts. Wartime casualties treated for hemorrhagic shock from vascular wounds were studied to report the 24-hour transfusion requirements, graft patency, and amputation-free survival for major vascular injuries.

METHODS: Joint Theater Trauma Registry data from August 2006 to April 2011 (56 months) were retrospectively reviewed. Included were casualties with a vascular injury who presented to US combat support hospitals in Iraq or Afghanistan. Amputation-free survival and graft patency were determined from record and imaging review.

RESULTS: The study group consisted of 497 severely wounded local national and military casualties (mean [SD] Injury Severity Score [ISS], 17 [8.5]) presenting with acidosis (pH 7.29 [0.15]), tachycardia (heart rate, 110 [29.31]), and coagulopathy (international normalized ratio, 1.6 [2.33]). Given DCR and early management of vascular injury, blood pressure, heart rate, temperature, hemoglobin, and base deficit improved promptly ($p < 0.05$) by intensive care unit admission. Transfusion requirements included packed red blood cells (15 [13] U; range, 1 70 U), fresh frozen plasma (14 [13] U; range, 1 72 U), cryoprecipitate (13 [15] U; range, 1 49 U), and platelets (8 [6] U; range, 1 36 U). Mean operative time was 232 minutes (range, 16 763 minutes). US casualties (n 111) had limb salvage attempted for 113 extremity vascular injuries (3 [2%] iliac, 33 [30%] femoral, 23 [20%] popliteal, 13 [12%] tibial, 33 [30%] brachial, 4 [3%] ulnar, and 4 [(3%] radial). In this subgroup, 28 (25%) were revascularized by a primary repair or end anastomosis, 80 (71%) were revascularized by saphenovenous grafts, and 5 (4%) were revascularized by prosthetic grafts. The follow-up ranged from 29 days to 1,079 days, (mean, 347 days), during which 96 grafts (84.9%) remained patent, 16 casualties (14.2%) required a delayed amputation, and 110 (99.1%) survived. Popliteal injuries had the highest amputation rate (7 of 23, 30.4%). The amputation-free survival was 84%.

CONCLUSION: In severely wounded casualties, wartime surgical strategies to save both life and limb evidently permit definitive procedures at initial surgery with excellent limb salvage results. This outcome analysis in a large cohort can help to refine surgical judgment and support contemporary DCR practices for major vascular injury. (*J Trauma Acute Care Surg*. 2012;73: 1517 1524. Copyright © 2012 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Epidemiologic study, level III; therapeutic study, level V.

KEY WORDS: Vascular trauma; massive transfusion; damage control; resuscitation; combat vascular injury; extremity trauma.

The current wars in Iraq and Afghanistan have been prolonged US military operations. Hemorrhage from extremity injury remains the leading cause of preventable death in combat.[1] Moreover, it has been recently reported that the rate of vascular injury in modern combat is five times that reported in previous wars and varies according to the theater of war, mechanism of injury, and operational tempo.[1,2] During the current war, changes in attitude toward tourniquet use and damage-control resuscitation (DCR) have permitted a consolidated effort to prevent hemorrhagic death and to treat battlefield vascular injury.[3,4] The resultant rise in extremity vascular injury presenting for care on the modern battlefield now is a major focus of surgical training for trauma readiness.[1,3]

At the start of the current war (2001–2003), teaching was based on principles learned in Vietnam; although every attempt was made to salvage wounded-extremities amputation was sometimes necessary to save lives in the most severely injured casualties.[5] In 2007, Borgman et al.[6] reported in casualties requiring massive transfusion that a high 1:1.4 plasma–to–red blood cell (RBC) ratio was independently associated with improved survival by decreasing death from hemorrhage.[6] This early experience during the war in Iraq demonstrated that casualties treated with DCR principles including early administration of blood products and optimal ratios of fresh packed RBCs (PRBCs) and plasma and platelets could achieve early

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hemodynamic stability.[6] This work has prompted us to study DCR during immediate vascular reconstructions the role on amputation-free survival for those with combat-related vascular injury.[7]

We aimed to provide a comprehensive report of the military vascular injury database and secondarily evaluate various limb salvage rates based on the type of vessel injury with the current military resuscitation strategies.

This modern analysis may help refine surgical judgment and evidence current resuscitation practices that seem to allow the pursuit of both lifesaving and limb-salvaging interventions.

PATIENTS AND METHODS

We designed a retrospective study using Joint Theater Trauma Registry (JTTR) records to evaluate the outcome of extremity arterial grafts among host national and military combat casualties. Any host national civilian or military casualty that presented with a pulseless limb from a penetrating arterial injury and admitted to a Level III combat support hospital located in Iraq (Baghdad or Balad) or Afghanistan (Bagram Air Field) between August 2006 to April 2011 (56 months) were included. Detainees were excluded. Demographic data were composed of casualty, age, sex, and mechanism of injury. Physiologic data included presenting vital signs (rectal temperature, blood pressure, heart rate [HR]), arterial pH, base deficit, hemoglobin (Hb) (g/dL), and international normalized ratio (INR). Changes in HR, temperature, as well as systolic blood pressure (SBP) and diastolic blood pressure (DBP) between the emergency department (ED) and the intensive care unit (ICU) were reflected as ΔHR, ΔT, ΔSBP, and ΔDBP, respectively. DCR was defined as the use of the following principles: permissive hypotension, correction of coagulopathy and acidosis, and limiting crystalloid infusions.

Blood product requirements (transfused PRBCs, fresh frozen plasma [FFP], cryoprecipitate, fresh whole blood [FWB], and platelets) within the first 24 hours were recorded. Recombinant factor VIIa (rFVIIa) doses administered in that period were also reported (1 dose, 90–120 μg/kg). Patients that required (FWB) a massive transfusion (≥10 U [PRBC + FWB] in 24 hours) or temporary shunt placement with delayed repair were noted. Following the arterial reconstruction, ICU vital signs and a postoperative Hb, arterial blood gas, and INR were compared with the presenting values documented in the ED.

Injury and care data collected regarding the injury and subsequent management included arterial location, associated venous trauma, revascularization technique, conduit type, graft configuration, need for temporary shunting or tourniquets, operative time, and heparin use. Descriptive statistics were used for demographic, physiologic, and transfusion data. Primary outcomes were physiologic improvement at ICU admission after surgery and graft patency (palpable pulse and normal ankle-brachial index > 0.9).

A Level I facility is defined as a far forward casualty collection site resourced for immediate lifesaving measures (airway, hemostasis), immobilization, and evacuation. A Level II facility has expanded resources for resuscitation and limited capability (simple repair or temporary vascular shunt) for vascular reconstruction. Level III facilities are resourced to provide all categories of surgical care within a theater of military operations and are the subject of this report. The study group was evacuated through Level I and Level II facilities before definitive repair or taken directly to the Level III hospital. US casualty survival at Levels IV or V was tracked. Secondary outcomes including delayed amputation, thrombotic and infectious graft failures, vascular reinterventions, complications, cause of death from central nervous system injury, exsanguinations, airway failure, multiple-system organ failure (in casualties surviving >24 hours), and arterial and venous thromboembolism were evaluated using the JTTR and available inpatient records from US military hospitals. These adverse events were recorded if present in the registry or records. Abbreviated Injury Scale (AIS, 2005 version) scores and Injury Severity Scores (ISS) were used from the JTTR.

Major amputation was limb loss at or near the ankle or wrist. The presence and indication for an amputation ipsilateral or contralateral to an extremity vascular repair was documented. Vascular limb salvage was defined as any lower- or upper-extremity vascular wound that was repaired with an expectation of permanent limb viability. Limb salvage failed if the casualty died or if the limb underwent a major amputation. If the graft failed (infection, rupture, thrombosis, stenosis, or reintervention by thrombectomy, revision, or replacement) but the limb remained viable, this was reported as a complication. Graft failures and amputation data were used to calculate the amputation rate (proportion of ipsilateral amputations divided by number of limbs repaired) and the amputation-free survival (survivors minus ipsilateral amputees divided by all casualties).

Descriptive statistics report the 30-day mortality and graft patency rate for the US casualty cohort only. Only US casualties could be followed up long term. Continuous data are presented as mean (SD) for parametric data or median (range) for nonparametric data. Paired t tests compared ED and ICU data. Statistical significance was set at $p < 0.05$. Statistical analysis was performed with SPSS 15.0 (SPSS, Inc. Chicago, IL). The protocol was approved (Iraq 06-009) by the combat support hospital's research committee and the Brooke Army Medical Center Institutional Review Board.

RESULTS

During the 56-month study, 497 casualties underwent a total of 523 vascular reconstructions of the upper extremity (171, 33%), lower extremity (323, 62%), or the neck, chest, and abdomen (29, 5%). The cohort was composed of US service members (219, 44%), Iraqi and Afghan Army, coalition forces, and host national civilians (278, 56%). The mean age of the study group was 25 years (range, 5–96 years; Fig. 1 and Table 1). The causes of penetrating trauma consisted of explosions and high-velocity gunshots wounds. Of 219 US casualties, 111 were followed up for graft patency and amputation-free survival, ranging from 29 days to 1,079 days (mean, 347 days), excluding casualties with ligations (67), venous

repairs (32), or nonextremity vascular reconstructions (6). Three patients were lost to follow-up.

Owing to the strategic location of various combat hospitals, transport times were short (approximately 30 minutes), resulting in minimal ischemic time for those evacuated with temporary vascular shunts. Casualties transferred from Level II facilities constituted a minority (84, 17%) of the cohort, and US casualties were almost universally given a fasciotomy (169 of 497, 34%) to minimize extremity ischemia before moving to a higher echelon of care.

The mean (SD) Glasgow Coma Scale (GCS) score was 13 (3.59), with a mean (SD) ISS of 17 (8.5). The mean (SD) temperature on arrival was 97.8°F (2.82°F) (417). Most patients presented in shock as a result of hemorrhage. At admission, 53% (263) of patients were acidotic (pH < 7.35), with a mean (SD) pH of 7.29 (0.15) (395), while 54% (267) were tachycardic (HR > 100 beats per minute), with a mean (SD) of 110 (29.3) (435). Furthermore, 46% (231) of the cohort were coagulopathic (INR > 1.5), with a mean (SD) of 1.6 (2.33) (348) at presentation. Moreover, half or 51% (253) of patients presented anemic (Hb < 13 g/dL) from hemorrhage, with a mean (SD) of 11.7 (3.07) g/dL (409). Hypotensive patients (SBP < 110) constituted 20% (97) of the study group, while the mean (SD) base deficit for the whole group was 6.1 (5.98). The mean (SD) SBP was 114 (29.9) (425), and the mean (SD) DBP was 66.3 (20.45) (417) at admission. Mean operative time was 232 minutes (range, 16–763 minutes). ICU physiology is summarized in Table 2.

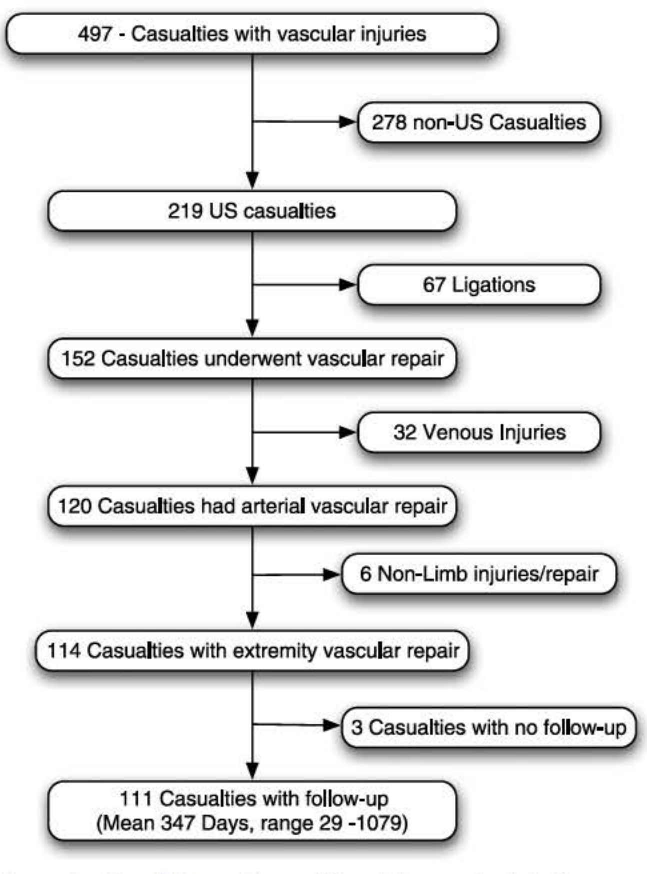

Figure 1. Breakdown of casualties with vascular injuries.

TABLE 1. Demographics and Averaged Physiologic Parameters on ED Arrival

Variable	All Patients
Age, median (range) (n 447), y	25, 5 96
ISS-05 (n 431)	17.1 (8.50)
GCS score (n 299)	13.33 (3.59)
SBP (n 425), mm Hg	114.16 (29.99)
DBP (n 417), mm Hg	66.29 (20.45)
HR (n 435), beats per minute	110.24 (29.31)
Temperature (n 417), °F	97.85 (2.82)
pH (n 395)	7.29 (0.15)
Base deficit (n 387), mEq/L	5.56 (6.32)
Hb (n 409), g/dL	11.76 (3.07)
INR (n 348)	1.62 (2.33)

Data are presented as mean (SD) unless otherwise specified.

Blood components within 24 hours were essential for DCR. Most casualties received PRBCs (67.6%, 335) and FFP (57.9%, 228), with a mean (SD) of 15 (13) U (range, 1–70 U) and 14 (13) U (range, 1–72 U) U, respectively, nearly a 1:1 ratio. A mean (SD) of 13 (15) U (range, 1–49 U) of cryoprecipitate (13%, 64) were administered, while 8 (6) U (range, 1–36 U) of platelets (33.6%, 167) were transfused. A mean (SD) of 5 U (range, 3–10 U) of warm FWB units was administered in 1% (5) of the casualties. rFVIIa was administered in both the ED and in the operating room (OR) to 6.2% (30) of casualties with a mean of 2 doses (1 dose, 90–120 μg/kg) (range, 2–6 doses). Crystalloid use had a mean (SD) of 5.8 (4.5) L (range, 1–28 L) in 94% (467), while massive transfusions (≥10 U of RBCs + FWB) were conducted in 34% (169). Overall, total components had a mean (SD) of 42 (39) U (range, 2–236 U), with 67.6% (336) being transfused (Table 3).

Tourniquets (316, 64%) were used frequently in the hospital and represented the first DCR effort by limiting blood loss. The majority of the casualty subset who underwent vascular reconstructions (213, 41%) (graft placement, bypass, or shunting with delayed repair) had interposition, reversed saphenovenous (SV) grafts (167, 78%) placed as the preferential technique. In the US casualty group, there were 17 graft failures (15%) among the 113 repairs achieving an 84.9% graft patency rate (96). Although the overall amputation rate was 14.2% (16), it was noticeably higher among those with popliteal arterial injuries (7, 30.4%). The rate of amputation diminished with femoral (4, 12.1%), tibial (2, 15.4%), brachial (2, 6.7%), and ulnar (1, 25%) injuries. Survival was 99.1% (110), and all-cause mortality was 0.9%, secondary to multiple-system organ failure (Table 4).

The 497 patients with 523 vascular injuries were treated with DCR principles (Table 5). Heparin (188, 38%) had a limited role and was administered in about a third of casualties. Temporary shunt placement with delayed reconstruction (84, 17%) was performed in both upper- and lower-extremity

TABLE 2. Physiologic Recovery Following Vascular Reconstruction

Variable	ED Arrival	ICU Admission	Δ (ED to ICU)	*p*
SBP, mm Hg	114.16 (29.99) (n 425)	127.85 (26.44) (n 375)	13.69	<0.0001
DBP, mm Hg	66.29 (20.45) (n 417)	67.25 (18.74) (n 377)	0.96	0.530
HR, beats per minute	110.24 (29.31) (n 435)	106.11 (24.43) (n 370)	4.13	<0.0005
Temperature, °F	97.85 (2.82) (n 417)	98.50 (1.57) (n 405)	0.65	<0.0001
pH	7.29 (0.15) (n 395)	7.31 (0.40) (n 211)	0.02	0.158
Base deficit, mEq/L	5.56 (6.32) (n 387)	2.90 (4.24) (n 211)	2.66	<0.0001
Hb, g/dL	11.76 (3.07) (n 409)	10.26 (2.55) (n 328)	1.5	<0.0001
INR	1.62 (2.33) (n 348)	1.39 (0.70) (n 278)	0.23	0.346
OR time, median (range), min		232, (16 763) (n 439)		

p values are derived from standard paired *t* tests.
Data are presented as mean (SD) unless otherwise specified.
ΔComparison of physiologic differences from ED arrival to ICU admission and 24 hours later following damage control and reconstruction.
Vitals signs and laboratory studies were taken immediately at ICU admission.

injuries, when the patient condition was deteriorating or if transfer to another facility was warranted.

DISCUSSION

The Global War on Terror, now a sustained conflict for more than a decade, has produced thousands of severely wounded US casualties and more than 500 major amputations.[1,8]

The war in Iraq and Afghanistan has focused much attention on prehospital hemorrhage control, DCR, and the repair of complex vascular injuries.[9–12] Although the rate of vascular injury is now fivefold higher than the Vietnam War, popliteal vascular injuries still account for nearly half of limb amputations and demonstrate the persistent challenges.[13–16] The amputation rate following vascular repair in the Vietnam and Korean wars, although improved over World War II, remains a poorly understood concept as vague definitions, variable denominators, and continued advances in care complicate comparison among conflicts.[14,15,17,18] Nonetheless, reporting results from the current wars serve as an important referent for surgeons that make life-over-limb decisions for vascular wounds with significant transfusion requirements in casualties with major physiologic derangements before arterial reconstruction.[19]

The latest edition of *the Emergency War Surgery Handbook*[5] recommends amputation over limb salvage for a number of broad, poorly defined examples of extremity arterial injury with physiologic derangement.[5] Evolving resuscitation practices early in this conflict permitted us to realize that repair is less risky, allowing longer and potentially more durable limb salvage reconstructions.[3,7,13] The emphasis on earlier and fresh (last into the blood bank and first out to the casualty) blood products in equal ratios, in contrast to only crystalloid infusions, has allowed surgeons to swiftly fix physiologic derangements in the early care of these casualties.[6,19–24] Most casualties reach the ICU warm, euvolemic, and fully resuscitated.[3,7] This approach meant that the OR is no longer a physiologically hostile environment, and surgeons can stay in the OR, repairing injuries as the physiology is normalized. DCR effectiveness has been reported by us in a case-control study of combat casualty care with vascular injuries.[3,13] In addition, we reported that DCR transfusion strategies yielded a 4-year amputation-free survival rate of 67% among casualties with popliteal arterial injuries, all of whom required a massive transfusion.[13] These femoropopliteal findings, a worst-case scenario, encouraged us to evaluate this large series of casualties including other vascular injuries. The aims of the present report were to identify the immediate physiologic response to the DCR strategy in the study group (N = 497) and determine long-term graft patency and amputation-free survival on a subgroup of US casualties with arterial extremity injury (n = 111). We report the amputation-free survival in only US casualties because host nationals are lost to follow-up soon after discharge.

In this study, 110 of 111 US casualties survived the immediate repair of an extremity arterial injury. This subgroup had a mean graft patency rate of 84.9% at 347 days (range, 29–1,079 days) and a primary amputation rate of 14.2% (16 of 113) after surgical treatment in the US military hospitals of Iraq and Afghanistan. This outcome is especially important given their initial physiologic derangements and may have strong implications for using fresh blood products in

TABLE 3. Summary of Mean 24-Hour Transfusion Requirements After DCR in 497 Casualties

Blood Component	Mean (SD)	Range
PRBCs, U	15 (13)	1 70
FFP, U	14 (13)	1 72
Cryoprecipitate, U	13 (15)	1 49
Platelets, U	8 (6)	1 36
Total components, U	42 (39)	2 236
Total crystalloid, L	5.8 (4.5)	1 28
Whole blood, U	6 U*	3 10
rFVIIa (1 dose, 90 120 g/kg)	2.1 doses†	2 6
Massive transfusion (>10 U per 24 h)	34% of study group	

*One percent of the study group.
†Six percent of the study group.
FFP, fresh frozen plasma or thawed plasma.

TABLE 4. Distribution and Management of 111 US Casualties With 113 Extremity Vascular Injuries

Artery	Primary Repair	SV Graft	Prosthetic	Repairs	No. Patients	Amputation	Survival	Follow-Up, Mean (Range), d
Iliac	1	1	1	3	3 (100%)		3 (100%)	347 (29 1,079)
Femoral	10	20	3	33	29 (87.9%)	4 (12.1%)	33 (100%)	
Popliteal	1	22		23*	16 (69.6%)	7 (30.4%)	22 (100%)	
Tibial	9	4		13	11 (84.6%)	2 (15.4%)	13 (100%)	
Brachial	4	28	1	33*	30 (90.9%)	2 (6.7%)	31 (96.9%)	
Ulnar	1	3		4	3 (75%)	1 (25%)	4 (100%)	
Radial	2	2		4	4 (100%)		4 (100%)	
Total	28	80	5	113	96 (84.9%)	16 (14.2%)	110 (99.1%)	

*One bilateral repair.

equal ratios when arterial reconstruction is attempted over a primary amputation. Based on these findings, we suggest that the current resuscitation practices have merit and that the *Emergency War Surgery Handbook*[5] should be updated to reflect this new information. Unreconstructible mangled extremities and severe ischemia precluding good recovery are important categories to identify when refining future amputation outcome data.

For those with intended limb salvage, we find that DCR was associated with a reversal of the initial acidosis, hypothermia, and coagulopathy seen in these critically injured casualties.[1,6] In the military, implementing a DCR strategy for vascular trauma is crucial, given that a quarter of all combat-related injuries arrive in hemorrhagic shock, with nearly a third in a coagulopathic and/or acidotic condition that requires damage-control strategies.[3] These are referents for civilian trauma care. Holcomb et al.[20] concluded that increased plasma-to-platelet-to-RBC ratios in massively transfused patients improved outcomes. Cotton et al.[25] have shown that patients who underwent damage-control surgery laparotomy and treated with DCR principles have also improved survival. The 99.1% survival rate observed among the US casualties undergoing an immediate vascular reconstruction in this study seems to be associated with the early release of blood products in balanced ratios for optimal resuscitation of hemorrhagic shock during the surgical management of the vascular injury.[20]

Although controversy surrounding the comparison between military and civilian trauma exists, the management and early outcome are comparable as a large recent civilian experience from Memphis documented an amputation rate of 24% in 102 patients with popliteal artery injuries.[26] Popliteal war wounds have been the subject of much attention, given high rates of amputation associated with ligation (72%) and repair (32%) in past wars.[14] Our reported amputation rate of 30.4% for this injury is consistent with other large reports. There has also been an impressive reduction in the overall amputation rate from 49% in World War II to 13% in the Korean War, and this rate remained similar through the Vietnam War.[17] In an orthopedic study on Grenada, the Gulf War, and Somalia, the overall amputation rates were 19%, 14%, and 14%, respectively.[27] Given our overall amputation rate in this study of 14.2% (16 of 113 extremity injuries), it is reasonable to consider that while the rates remain similar to earlier conflicts, the severity of injury may be worse.

The initial physiologic assessment and DCR began immediately in the ED based on vital signs, base deficit, and coagulopathy. An emergency release of 4 U of PRBCs and 4 U of thawed AB plasma awaited the casualty. Multiple extremity injuries or combined injuries of the abdomen or thorax with an isolated extremity injury triggered the massive transfusion protocol and, in some cases, an FWB drive, depending on the degree of shock. Transfusion requirements for the group were significant and should not be underestimated for these types of wounds. The mean total components were 42 U (range, 2–236 U). The mean PRBC products given for a vascular injury was 15 U. At 14 U, the plasma–to–packed cell ratio approximated 1:1, and more than one third of the group received a massive transfusion. Crystalloid use was kept to a minimum, with 94% receiving a mean (SD) of 5.8 (4.5) L in 24 hours. In this study, DCR practices were responsible for a significant improvement in physiologic parameters. By the time these patients arrived in the ICU, their physiologic parameters showed a significant ($p < 0.05$) reversal of the initial metabolic derangements. Table 2 shows statistically significant improvements in mean SBP, HR, temperature, Hb concentration, and base deficit. The INR values decreased from a mean of 1.62 in the ED to 1.39 in the ICU, but this was not statistically significant.

Explosive mechanisms now account for 78% of injuries in the wars in Iraq and Afghanistan, which is the highest proportion observed in any large-scale military conflict.[28] The likelihood of vascular injury with explosive munitions, shorter casualty evacuation times, and changes in survivability may account for the dramatic rise in the rate of injury during this war.[2] Forward-based surgical units have expanded the role of temporary shunting and delayed repair of vascular injury and has been demonstrated to be a very effective damage-control technique.[29,30] In some smaller facilities with a limited blood supply, temporary shunts were used to minimize the ischemic time.[29–31] In our study, 15% of patients were shunted until transferred to a combat support hospital or evacuation hospital with the capability to resuscitate and perform a definitive vascular repair.

Comparable to the Vietnam War, the preferred conduit is an autologous graft.[14,15] Half of all arterial reconstruction in our study was by saphenous grafts (181 of 362, 50%), and prosthetic graft use was limited to only 3% of the casualties (15 of 497) in this study.[32] Although many injuries are

TABLE 5. Distribution and Management of 497 Patients With 523 Vascular Injuries Using DCR and rFVIIa

Location/Vascular Injury	Suture	Patch	End-End	Prosthetic	SV Interposition	SV Bypass	Ligation	Thrombectomy	Total
Abdomen									
Splenic			1				2		3
Renal							1		1
Iliac	1		1	5			2		9
Hypogastric	1						1		2
Neck									
Carotid	2		4		2				8
Chest									
Aorta	1								1
Innominate			2						2
Upper extremity									
Subclavian	1		1	2	2		1		7
Axillary	1	1		1	4	2			9
Brachial	6	1	6	1	48	6	1	2	71
Ulnar	6	1	1	1	1	2	13		25
Radial		1	1		4		18		24
Lower extremity									
Common femoral	4		1	2	6	3	2	1	19
Superficial femoral	4	6	8	2	39	6	3	2	70
Popliteal			5		35	10	4	5	59
Tibial	6	1	5		9	2	28	1	52
Venous									
Saphenous							8		8
Radial							1		1
Brachial					2		9		11
Basilic							7		7
Cephalic	2						5		7
Jugular	1		1				5		7
Subclavian							2		2
Axillary	2						5		7
Hepatic	1						1		2
Splenic							2		2
Hypogastric							1		1
Iliac	3		1				11		15
Femoral	1		2		5		7		15
Superficial femoral	7	1	6	1	6		18	1	40
Tibial	1						13		14
Popliteal	1	1	3		4		13		22
Total	52	13	49	15	167	31	184	12	523

End-end, end-end anastomosis; suture, primary repair.

successfully managed with ligation, we find that repair of distal vascular injury (radial, ulnar, or tibial) was performed in 41 (41%) of 101 patients in contrast to much higher numbers of ligation observed in past conflicts.[14,15,17] The outcome of selective distal revascularization during this war has been recently reported by Burkhardt et al.[33] More than one third of femoral and popliteal injuries were associated with venous injury, and this finding is comparable with other publications.[34] Concomitant venous repair is strongly recommended for the reported benefits of reducing chronic edema and theoretically improving limb salvage with this approach.[35] However, in this setting, the rate of venous repair parallels that of venous ligation for femoropopliteal injuries.[35] It is crucial to ensure the graft remains well covered, and the wound size is often a major determinant for placing an interposition graft (small wound) or routing SV graft (large wound) around the zone of injury (bypass).[3] Graft patency was determined by continuous wave Doppler assessment, ankle-brachial index, and completion imaging (catheter-based angiogram) at arrival in the United States and then followed quarterly until discharged. The rational and technical aspects of our operative approach have been published previously.[3] Last, it is important to emphasize that the current results are from medical operations in a highly mature and developed combat theater and may not reflect what was seen in earlier phases of combat operations or in a less developed combat environment.

STUDY LIMITATIONS

Wartime reporting, challenged by tactical conditions, depends on accurate registry data to capture all the vascular repairs, including type, and complications. Amputation data sometimes extracted from an orthopedic clinical note may not address questions regarding the status of the arterial reconstruction at the time of amputation. This heterogeneous study may provide useful data for future analysis. However, Iraqi and Afghan casualties had limited follow-up information, and although DCR was used, not all casualties required the same level of resuscitation, and therefore, the reader must be cautioned when drawing conclusions. Furthermore, casualties once discharged from the military health care system are difficult to follow up. Graft surveillance is an ongoing process, and further studies are required to establish the ultimate long-term impact on limb salvage. Most importantly, we do not have a concurrent or retrospective control group of casualties with similar injuries treated with non-DCR principles, demonstrating inferior results or increased amputation rates. However, it is the opinion of experienced combat surgeons that many of the limbs successfully saved would have been amputated in previous conflicts or earlier in the current war.

Despite these limitations, the findings of this study are novel and have merit. This DCR approach is well supported by the current civilian trauma literature, and important data regarding the relationship of these DCR strategies for successful limb salvage in severely injured casualties provide further support for deploying surgeons to repair limbs when the DCR resources are available. These wartime data show excellent early survival coupled with a comparable amputation-free survival rate with the previous studies of this conflict.

CONCLUSION

Previous war surgery principles were that casualties in shock with the most severe orthopedic and vascular injuries should have limbs sacrificed to save lives, but now with full use of DCR principles in the ED, blood bank, OR, and ICUs, results indicate that significant surgical efforts can be safely expended, saving many limbs with excellent results. These strategies for both lifesaving and limb-saving interventions seem to permit definitive procedures at the initial operative setting in severely wounded casualties. This article provides an outcome analysis in a large cohort that can serve to refine surgical judgment and support contemporary DCR practices in the setting of major vascular injury.

AUTHORSHIP

A.D. and C.J.F. designed the study. A.D., B.P., and C.J.F. searched the literature. A.D., B.P., J.B.H., and C.J.F. analyzed the data. All authors interpreted the data, wrote and critically revised the manuscript. C.J.F. gave final approval.

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DISCLOSURE

The authors declare no conflicts of interest.

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EDITORIAL CRITIQUE

There is an oft-quoted proverb when discussing combat casualty care, which states that "the only winner in war is medicine." As we emerge from over a decade of sustained combat operations in Iraq and Afghanistan, this truism has again been widely validated. Dr. Fox and his group at Walter Reed Army Medical Center have performed an important analysis of extremity vascular injuries in the modern battlefield, and I suspect that this will become the definitive historical reference on this topic from the Global War on Terrorism experience. Despite the increased severity of injuries associated with modern weaponry and explosives, a commendable limb-salvage rate (86%) has been achieved. Although there are inherent limitations to any retrospective combat study, their detailed long-term data on the subset of 111 patients provides invaluable insights and lessons for current and future generations of trauma surgeons.

This series does serve to reinforce one of the most basic tenets of military medicine—the need for well-trained surgeons who are versed in the basics of open vascular repair and reconstruction. Although this goal seems self-evident, it is increasingly divergent with the current trends in both vascular surgery and resident education. The field of vascular surgery continues to drift further away from its general surgery origins in favor of increased specialization. Open vascular surgical cases are becoming increasingly rare events, in favor of endovascular and catheter-based procedures—techniques not commonly available in the combat setting. A second-order effect of this trend is that graduating residents may lack the basic skills in traditional vascular surgery that are still required on the modern battlefield. The development of trauma training courses such as Advanced Trauma Operative Management and Advanced Surgical Skills for Exposure in Trauma are a good start, but this looming crisis for military medicine will require innovative action if we are to avoid the degradation or loss of this critical skill set. We owe it to our trainees, colleagues, and most importantly to our patients.

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